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The Institute of Research at St. Louis, France, is involved in research in ballistics, chemistry of explosives, and detonations, aerodynamics of wings and slender bodies, acoustics, lasers, and measurements techniques. This report is a review of some of the research and facilities.

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FACILITIES AND RESEARCH AT THE FRENCH-GERMAN INSTITUTE OF RESEARCH AT SAINT-LOUIS

1 INTRODUCTION

The Institute of Research at Saint-Louis (ISL) was founded in 1959 and is equally funded by the French and German governments. Its program of research is based on a 3-year program arrived at jointly between the two countries through a high-level advisory committee consisting principally of members of the defense establishment of each country. There is also a detailed yearly research plan. In order to facilitate creativity among the researchers there is an "exploratory research program" which permits the individual researcher to initiate new activities within the mission of the institute. Up to 20 percent of the researcher's time may be devoted to exploratory research which can lead to new directions and emphasis for the institute if successful. Since ISL is a joint French and German government activity the administrative staff is perhaps greater than normal. I had an opportunity to talk to both the French and German directors of the Institute.

There are about 450 people employed at ISL, of whom approximately 90 are professionals at the doctorate level. Although most of the support people are French, the scientific and professional staff is equally divided between French and German scientists or engineers.

There is strong emphasis on experimental activities connected with ballistics and armament. Thus ISL is similar to the Ballistic Research Laboratory in Aberdeen, Maryland. The 40 research groups, organized in 11 departments, generate about 200 reports, papers, and presentations a year. The research at ISL is in several scientific domains including ballistics, chemistry of explosives and detonations, aerodynamics of wings and slender bodies, acoustics, lasers, and measurement techniques. A recent review of the institute (in German and French) is available from ISL, 12 rue del'Industrie F, 08301, Saint-Louis, France.

My principal host for the visit was Dr. H. Pfeifer, head of the Laser Measurements Department. I will begin this discussion with an account of the more conventional testing facilities and then proceed to facilities using the more modern techniques involving lasers.

2 SHOCK TUBE FACILITIES

My first visit was with Dr. Smeets, who is in charge of the shock tube facilities. A high-pressure shock tube, which has the capability of using unheated hydrogen as a driver gas, is contained in a relatively new building (1978). The shock tube is well designed and since it is being used in a relatively innovative manner, it is still in operation. Original work was done on heat transfer studies of high-temperature gas to spherical shapes. In this case the shock tube was used to generate a high-temperature reservoir which was further expanded in a nozzle.

More recent work in the facility has been concerned with a fairly fundamental investigation of the noise generated by supersonic jets. Particular attention was devoted to a study of shear noise. Some very clever flow visualizations of the jet generated by the shock tube helped illustrate the noise sources. Present work is directed at simulation of the flow in gun barrels by means of the shock tube. This is actually a detailed study of the turbulent boundary layer behind a piston in a tube or barrel. F. Seiler is directing this effort, and while some of his earlier work on simulation is in English the reports on the measurements are in German.

3 AEROBALLISTICS RANGE

The aeroballistics range is directed by Dr. Giraud. This area is a traditional one for ISL. Work in aeroballistics has resulted in the development of different types of flechettes which are designed to penetrate armor. Extensive investigations have also been conducted on caseless ammunition and combustible cases as well as subcaliber projectiles. The range, being a well-designed experimental facility, has the typical capability of taking shadowgraphs and photos of the projectiles in flight. Some studies by Dr. V.F. Lehr are directed at electromagnetic acceleration of projectiles. As the German technical director, Dr. Vogel, indicated, ballistic technology is a mature science which has reached a plateau. Electromagnetic acceleration is expected to be a fruitful area of innovation. He indicated that similar work was going on at the Naval Weapons Center, China Lake.

4 BALLISTICS AND MATHEMATICS

Connected with the flechette investigations is a group in terminal ballistics and mathematics (Mr. Wollman and Mr. Hoog). This group is concerned with both tank destruction by long, narrow, highly kinetic projectiles and the protection of tanks from such projectiles. Experimental measurements consist of x-ray photographs of the penetration of armor and armor baffles by high-kinetic-energy projectiles. The mathematical aspect of the problem is the numerical simulation of the process. Wollman and Hoog use an IBM 3032 computer. At present the numerical simulations involve axially symmetric calculations which depend critically on the unknown equation of state at the high temperature and pressure conditions characteristic of penetration. The experimental measurements of the deformation of the armor serve as a method of predicting the equation of state of the armor. With the equation of state determined (the present emphasis) and with a further extension to nonaxisymetric calculations realistic numerical simulation of kinetic armor penetration would perhaps be possible.

5 LIGHT GAS GUN FACILITY

The light gas gun facility is connected with the experimental and theoretical aerodynamics group. People at the facility have done ablation studies on sabot-launched objects and obtained surface regression rates. (I obtained work similar to this using a light gas gun in 1966, and work along this line is still being done at the Arnold Engineering Development Center [AEDC], in Tullahoma, Tennessee.) More interesting were the aerodynamic measurements and calculations conducted on a wing with spoiler by Czichowsky, et al., (1985) and another experiment conducted on a wing profile at various angles of attack (Jaeggy et al., 1986). These last two references, which appear to be the typical method of publication, are conference presentations, with one in German and the other in French. In the first experiment, detailed laser Doppler anemometry (LDA) measurements and flow visualization were obtained of the flow along the wing and spoiler as well as the Karman vortex sheet developed by the spoiler. The LDA measurements were time-keyed to the shedding frequency of the vortex sheet, and one could by this means distinguish the coherent structure from the turbulence. Figure 1, taken from the report by Czichowsky et al., shows the supercritical airfoil and spoiler. Measurements were made in subsonic flow at a Strouhal number of 0.21. Further measurements at Office National d'Etudes et de Recherches Aérospatiales (ONERA) and Institute de Fluid Mechanic de Lille (IMFL) on the same profile are referred to in the paper. Two approaches to the numerical solution were tried. In the first case a nonviscous model using several vortices (a method similar to some work of T. Sarpkaya) was used. Further numerical calculations were tried with the full Navier-Stokes equations but this is a

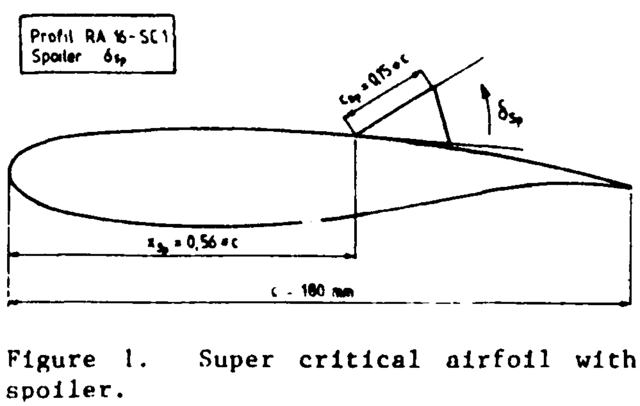

Figure 1. Super critical airfoil with spoiler.

very difficult problem. Although some results were reported, detailed numerical comparisons are perhaps too much to expect.

In the second paper or experiment concerning flow measurements around a NACA-65213 profile one can expect detailed numerical comparisons. In addition to pressure measurements the velocities and turbulence were obtained, as reported in the previous experiment with a two-color computer-controlled LDA system. The flow velocity was 27 m/s and the Reynolds number was about 240,000. The angle of attack of the profile was varied up to 8.5 degrees. Several methods of calculation were used to compare the numerical calculations with the experimental results. GENMIX, the algorithm by Spalding, produced the best comparisons. The k-ϵ model was, however, modified according to a suggestion by Rodi and Scheuerer. The location of the rear separation point presents great difficulty and the current method is to fiddle with the viscosity law. This can, unfortunately, lead to different closure conditions for different experiments. The two experiments are clearly state-of-the-art work. It is detailed comparisons of experiment and theory such as these that are going to further the understanding of complex flow fields.

6 TELEMETRY CAPABILITY

ISL has developed extensive telemetry capability for gun-launched projectiles which sustain acceleration levels of over 100,000 g. Dr. V. Wegner reviewed for me the history of the development of their present telemetry devices; it was interesting to see the effect of new technology of semiconductor devices and microchips on the size of the telemetry equipment. I also had a discussion concerning some of their more current work, particularly the work on the TAPIR system. This system is fairly well known but the simplicity of the flight path correction system is still impressive. There is the further advantage that the target does not need to be continuously illuminated by a laser beam during the engagement. Computer facilities are quite good at ISL, and I was given a computer demonstration (on a PC) of the TAPIR targeting system. My trips were unclassified but since ISL works for both the defense agencies of Germany and France it is probably that I did not have access to all projects.

7 OPTICAL SPECTROSCOPY

In the area of optical spectroscopy I talked to Mr. H. Mach. A. Eichhorn is conducting an active experiment in Coherent Anti-Stokes Radiation (CARS), which can be used to determine density and temperature of gas mixtures. Since this is a relatively new technique, it was good to have a demonstration and discussion of the theory involved. Application of CARS to the typical munitions explosion and to jets of molten metals, which are of interest to ISL, would appear to me to present formidable difficulties. The CARS study fitted in with my perception that ISL has an active basic research program looking at modern techniques as they apply to any of their research areas. Mach has applied a series of techniques to the determination of nonsteady phenomena associated with combustion of solid gun propellants, flow field measurements in reacting muzzle exhaust flows, and measurements in gun-barrel boundary layers. He is currently measuring the surface temperature and velocity of a collapsing copper cone. The temperature is determined by means of two infrared measurements and the velocity by an acoustic sensor.

8 LASER LABORATORY

The laser laboratory is headed by Dr. M. Hugenschmidt. I was impressed by the equipment in the laboratory which includes a repetitively pulsed high-average-power CO_2 laser, a new excimer laser, and a large neodymium YAG laser. Much of their work has been in the area of investigating the effect of lasers on armament and in determining counter measures against a laser weapon. I had an impression that the laser laboratory was well equipped but that there was a shortage of people working with the devices.

9 OPTICS DEPARTMENT

The optics department is directed by Professor Smigielski, who is at present at a university in the US. Some rather fundamental activities in the area of coherent optics is conducted in the department. Mr. H. Fagot and Royer of the optics department discussed with me their work in microholography. The holographic recording of a cloud of particles permits the determination of the shape, size, and location of the particles in three dimensions. By use of double or multiple pulsing (the particle image velocimetry [PIV]), it is also possible to determine the velocity of the particle.

Fagot and Royer have used the microholographic technique to investigate the size distribution of icing fog and the fuel atomization of the Ariane rocket. Another recent application of holograph by ISL has been the first elementary particle tracks in the bubble chamber of CERN at Geneva. In 1983 ISL made the first cineholograph, which was a holographic movie of diffusely reflecting objects. Although this has somewhat the aspect of show business, there are possibilities for this technique in visualization of defects and nondestructive testing of aircraft parts.

10 APPLICATIONS OF LDA TECHNIQUES TO MEASUREMENTS

For me, some of the more interesting discussions were conducted with Dr. Pfeifer, Dr. Schäfer, and Mr. Sommer on the applications of LDA techniques to measurements. This may reflect my own involvement in LDA. Pfeifer's department holds some of the fundamental patents in three-component LDA in France. They have work on blowdown wind tunnels for ONERA and DFVLR in Germany, and they have a data exchange agreement with AEDC in Tennessee. One of the problems in the application of LDA to rapidly changing flows is the correct setting of the filters on the counters so that only the desired signal is processed and not extraneous noise. In a steady-state case the filter can be readily adjusted, but in the case of an automatic traverse under computer control, such as through a boundary layer, the velocity changes rapidly and the filter needs to change dynamically with the velocity. Pfeifer and his associates have developed an automatic device for adjustment of the filter bank (Pfeifer et al., 1984).

Particle size distribution is always a critical LDA question, and the group has done some characterization of distribution properties by means of whisker collectors. In addition to developing fundamental techniques for LDA the group has applied the technique to a wide range of difficult flow fields. Thus, there are measurements on high-speed and high-temperature exhaust gases (Schäfer, 1983), studies of high-speed combustion flows (Schäfer, 1984a) using TiO_2 as particles and the study of transonic shock boundary-layer interactions (Schäfer, 1984b). The high-speed exhaust study (Schäfer, 1982) has some earlier work on coherent structure determined by two-point correlation. The long-length LDA device (Somer and Pfeifer, 1986) has a particularly compact structure and has been used up to 100 meters; the YAG laser, frequency doubled, is used as the source with a C-14 telescope by coherent optics as a receiver. (Long-range velocimetry is also being conducted at Ames in California.) There have been, also, a series of publications concerning measurements in wakes of bluff bodies, turbulence wakes, and further measurements of supercritical profile with spoiler by Mr. C. Berner and Mr. G. Koerber, among others. In the area of LDA there is certainly no technological gap with America. Pfeifer's department is doing first-rate research in the application and development of LDA techniques.

11 CONCLUSIONS

Although one might think that a laboratory devoted to ballistics and armament might not involve basic and applied research, I did not find this to be the case at ISL. There are some conventional equipment and apparatus at the laboratory but there is some very innovative work going on in the application of new optical and laser techniques to the research areas outlined above. There is a strong effort to keep ISL creative and this requires the strong emphasis that the Institute has on basic and applied research. I have a list of pertinent reference which I can make available to interested parties.

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